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Selection of Core-shell Material-based Electromagnetic Wave Absorbers in 2-18 GHz using TOPSIS and VIKOR Ranking Methods

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ABSTRACT

Electromagnetic (EM) wave has become an integral part of this electronics dominated era with extensive application in wireless communication, health care, and military applications. This has led to the development of EM wave absorbers for camouflaging the military warheads from the enemy radar tracking systems. The development of these absorbers requires considerable resources viz. time, energy, raw materials and cost. This creates a need for selection of a better absorber from the existing ones rather than the development of a new one to save the valuable resources. The judicious selection of an efficient microwave absorber requires ranking the existing absorbers based on selection criteria. For the first time, an attempt has been made to apply the concept of multi-criteria decision-making methods viz. VIKOR and TOPSIS in ranking the microwave absorbers. Core-shell materials provides enhanced EM wave attenuation owing to their hierarchical composite structure which provides a better approach to tune the dielectric and magnetic properties of the composite for obtaining good impedance matching resulting into enhanced absorption. In the present work, magnitude of minimum reflection co-efficient value, absorber thickness, deviation from the central frequency (i.e. 10 GHz) and -10 dB bandwidth have been selected as the criteria for judiciously selecting suitable core-shell based EM wave absorbers in 2-18 GHz. The selected criterion has been assigned distinct weights using Analytic Hierarchy Process (AHP). The AHP derived weights have been employed in TOPSIS and VIKOR analysis for the absorbers ranking and selection.

Keywords: Electromagnetic wave absorber; Core-shell materials; AHP; TOPSIS; VIKOR

1. INTRODUCTION

In this technologically advancing world, microwave absorbing materials play a very significant and instrumental role in the areas of health care, electronic instruments reliability and national defence. Minimizing the radiation problems, electromagnetic pollution problems and reducing the radar cross-section of the military units are the major focus areas where the applicability of microwave absorption arises. The importance of microwave absorbing materials in the modern society has prompted the researchers to develop high-performance microwave absorbers with characteristic features of high absorption, wider bandwidth, low density and less thickness[1]. Different approaches to develop microwave absorbers have been tried such as variation in particle size of absorber[2], doping[3], process parameters[4,5], secondary phase dispersion[6,7], multi layering[8] and implementation of frequency selective surfaces[9]. Since its inception, ceramics and ferrites based composite materials have been extensively used as microwave absorbing materials. However, the traditional ceramics and ferrites based absorbers do not possess broadband characteristics to satisfy the modern requirement and also light-weight criteria at the same time. This has led to the emergence of hierarchical core-shell materials in recent times with superior absorption characteristics. The materials having core-shell structure have attracted the attention of researchers around the globe in view of their superior properties such as high interfacial polarisation, greater impedance matching, and synergistic effect. Therefore, researchers around the globe are developing core-shell structured materials for EM wave absorption. Recently, a large number of core-shell materials have been developed which makes the selection of a particular absorber quite difficult. Therefore, in order to judiciously address the problem of material selection and subsequently save the valuable resources used for development of new materials, the multi-criteria decision making methods such as TOPSIS and VIKOR can be employed[10,11]. The present work, elucidates a novel effort to highlight the utility of TOPSIS and VIKOR approaches by ranking available core-shell based absorbers from literatures. Till date, no open literature is available for the selection of EM wave absorbers using TOPSIS and VIKOR approaches. Therefore, this paper presents an idea to rank the absorbers according to their merit for their judicious selection in practical applications.

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2. RESEARCH METHODOLOGY

2.1 Selection of Material Attributes

In this study, the material database consisting of 14 numbers of core-shell based EM absorbers have been created from different research articles as shown in Table 1 which serves as the decision matrix and ranked using TOPSIS and VIKOR approaches.

The attributes for selection process has been selected on the basis of most influencing parameters for EM wave absorption.

The modulus of reflection co-efficient (|RC|), absorber thickness (t), effective absorption bandwidth (EAB) corresponding to -10 dB and deviation from the central frequency (Δ) i.e. (10 GHz) were decided to be the selection criteria which are important parameters for deciding a better absorber. An efficient EM wave absorber will have a high value of |RC|, large EAB in a given frequency range, small *t* for cost-effectiveness and small Δ for an effective absorber functioning in X and Ku bands. Also, small Δ ensures that the absorber can be easily tuned to operate in either the X or Ku band by varying the materials composition or absorber thickness. The research methodology for material selection has been depicted in Fig. 1.

2.2 Analytic Hierarchy Process based Weight Assignment to the Attributes

The analytic hierarchy process (AHP) method is used to assign weights to the selected attributes in hierarchical multi-criteria based decision-making problems. In AHP, a comparative judgment between the attributes is done and each attribute is assigned a certain weight based on the comparative judgment. The steps followed in AHP are:

Step 1: Construction of a comparison matrix.

$$\begin{bmatrix} A_{11}\dots A_{1j}\dots A_{1s} \\ A_{i1}\dots A_{ij}\dots A_{is} \\ A_{r1}\dots A_{rj}\dots A_{rs} \end{bmatrix}; A_{ii}=1; A_{ij}=1/A_{ji}; A_{ji}\neq 0 \quad (1)$$

$$i=1,2,..r;\ j=1,2,..s$$

where A_{ij} denotes the attributes. A scale of digits between 1 and 9 describes the relative importance between two attributes. The digit '1' denotes "equal importance", '3' denotes "slightly higher importance", '5' denotes "much higher importance as compared to the other", '7' denotes "very important" and '9' denotes "extremely important"[26].

Step 2: The comparative weights are calculated using the eigenvalues from the matrix as in Eqn. (2).

$$(A-\lambda_{max} I)w=0 \quad (2)$$

where, λ_{max} represents the largest eigenvalue with w as the eigenvector.

Step 3: Checking the consistency and accuracy of the calculated weights by Eqns (3-4).

$$CI=(\lambda_{max}-r)/(r-1) \quad (3)$$

where, the index for consistency is denoted by *CI* and *r* represents the number of selected attributes.

$$CR=\frac{CI}{RI} \quad (4)$$

where, *CR* and *RI* represents the consistency ratio and random index respectively. The value of *RI* is decided on the basis of number of attributes is given in Table 2[27]. The comparison between the attributes is acceptable only if $CR\leq 0.1$. In this case, reliable results can be obtained.

Table 2. Value of RI according to the number of attributes

No. of attributes	2	3	4	5	6	7
RI	0.00	0.58	0.90	1.12	1.24	1.35

2.3 TOPSIS based ranking method

The following steps are involved in TOPSIS based ranking approach[26]:

Step 1: Normalisation of the numerical values of the attributes in the decision matrix using Eqn. (5).

$$k_{ij}=\frac{A_{ij}}{\sqrt{\sum_{j=1}^{s} A_{ij}^2}} \quad (5)$$

Step 2: Columns of the normalised matrix is multiplied by assigned weights as in Eqn. (6)

Table 1. Material database representing the numerical values of the attributes

Materials	Material code	Reflection Co-efficient '|RC|' (dB)	Effective absorption bandwidth 'EAB' (GHz)	Absorber thickness 't' (mm)	Deviation from central frequency i.e. 10 GHz (Δ)	Ref.
CoFe2O4@CNT	M1	32.80	5.70	2.00	1.70	[12]
CoFe2O4@Graphene	M2	42.00	4.59	2.00	2.90	[13]
FeSn2@onion-like C	M3	48.60	3.20	3.50	1.84	[14]
SiC@SiO2	M4	32.72	5.32	3.50	3.84	[15]
Cu@Ni	M5	32.20	1.60	2.00	1.80	[16]
Ni0.5Co0.5(OH)2@PANI	M6	39.80	3.10	2.50	3.60	[17]
Graphene@NiO@PANI	M7	37.50	4.90	3.50	3.40	[18]
SiC@C	M8	39.20	8.00	1.5	6.40	[19]
Fe@ZnO	M9	22.33	4.00	2.43	8.00	[20]
FeCo@C	M10	40.00	13.40	2.50	0.80	[21]
Co3Fe7@C	M11	44.40	3.20	1.60	3.00	[22]
FeNi3@SiO2@Rgo	M12	49.40	3.38	3.80	1.36	[23]
ZnO@C@Co3ZnC	M13	62.90	5.50	2.20	3.90	[24]
Co@C	M14	42.00	11.31	3.00	0.56	[25]

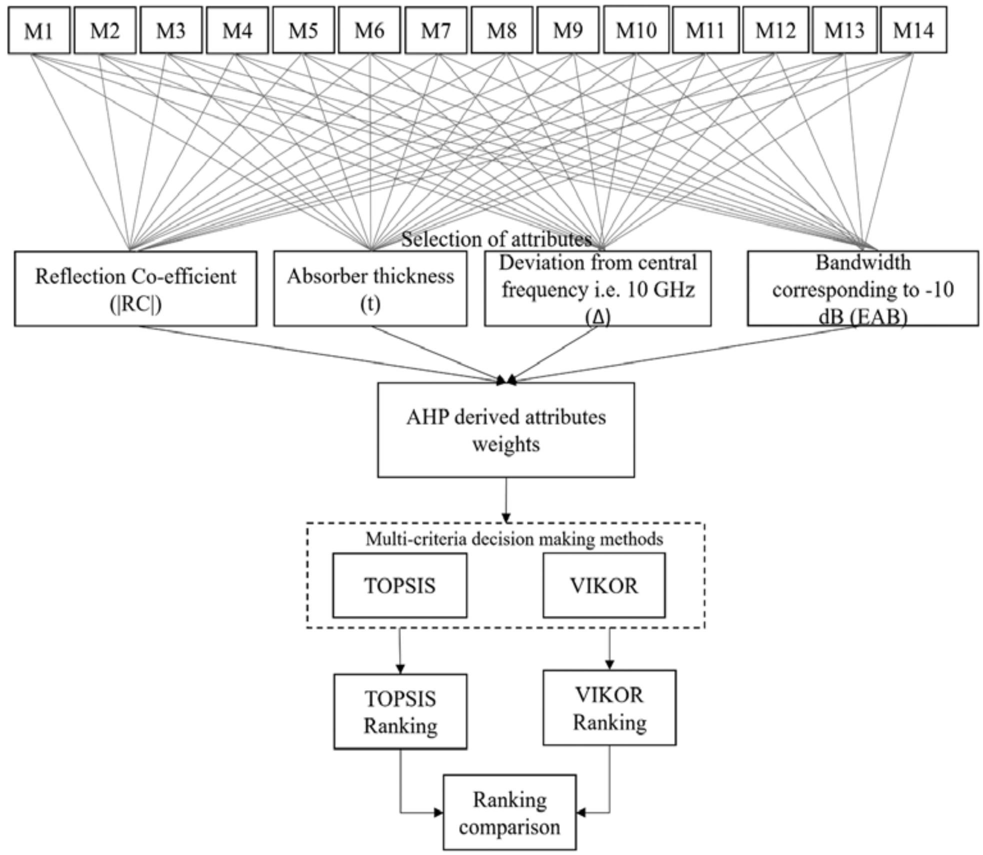

Figure 1. Flowchart showing the research methodology for ranking the EM absorbers.

$$G_{ij} = k_{ij} w_i \quad (6)$$

Step 3: Determination of ideal and worst solutions using Eqns. (7) and (8), respectively.

$$\left\{G_1^+, G_2^+, ..G_i^+\right\} = \left\{\underset{j}{Max}\, G_{ij} \middle| i \in K), (\underset{j}{Min}\, G_{ij} \mid i \in K') \right\} \quad (7)$$

$$\left\{G_1^-, G_2^-, ..G_i^-\right\} = \left\{(\underset{j}{Min}\, G_{ij} \mid i \in K), (\underset{j}{Max}\, G_{ij} \mid i \in K') \mid \right\} \quad (8)$$

where, K represents beneficial criteria set and K' represents cost criteria (non-beneficial) set.

Step 4: Euclidean distances from the ideal and worst solutions are calculated using Eqns. (9) and (10), respectively.

$$P_j^+ = \left\{\sum_{i=1}^{r} (G_{ij} - G_i^+)^2\right\}^{0.5} \quad (9)$$

$$P_j^- = \left\{\sum_{i=1}^{r} (G_{ij} - G_i^-)^2\right\}^{0.5} \quad (10)$$

Step 5: The relative closeness to the ideal solution is calculated using Eqn. (11) and represented by Q_j. For good rank, the value of Q_j should be high.

$$Q_j = \frac{P_j^-}{P_j^+ + P_j^-}; 0 \le Q_j \le 1 \quad (11)$$

2.4 VIKOR-based Ranking Method

The VIKOR method is a compromise solution method to rank the alternatives. The following steps are involved in VIKOR approach[26]:

Step 1: $(A_{ij})_{max}$ and $(A_{ij})_{min}$ representing the best and worst values are calculated from the decision matrix.

Step 2: Eqns (12) and (13) are employed to calculate the values of X_j and Y_j, respectively.

$$X_j = \sum_{i=1}^{r} w_i [(A_{ij})_{max} - A_{ij}] / [(A_{ij})_{max} - (A_{ij})_{min}] \quad (12)$$

$$Y_j = Max^n of \left\{ w_i \left[\sum_{i=1}^{r} w_i \left[\left(A_{ij}\right)_{max} - A_{ij} \right] \right] / \left[(A_{ij})_{max} - (A_{ij})_{min} \right] \right\} \quad (13)$$

Step 3: The VIKOR index Z_j is calculated for ranking using Eqn (14) with the value of v taken as 0.5. A smaller value of Z_j indicates better rank.

$$Z_j = \upsilon((X_j - X_{j\,min}) / (X_{j\,max} - X_{j\,min})) + (1 - \upsilon)((Y_j - Y_{j\,min}) / (Y_{j\,max} - Y_{j\,min})) \quad (14)$$

3. RESULTS AND DISCUSSION

This section shows the utility of AHP based TOPSIS and VIKOR approaches in ranking the core-shell based EM wave absorbers in the 2-18 GHz frequency range.

The above algorithms for weights determination and subsequently ranking using TOPSIS and VIKOR were applied to the EM wave absorber selection problem.

3.1 AHP Derived Weights

The AHP algorithm has been used to assign the weights of the attributes. The matrix for pairwise attributes comparison is depicted in Table 3. The matrix has been utilised for calculating the corresponding weights.

Table 3. Matrix for pairwise attributes comparison

	|RC|	EAB	*t*	Δ
|RC|	1	1	2	7
EAB	1	1	2	7
t	1/2	1/2	1	5
Δ	1/7	1/7	1/5	1

The calculated CI and CR values are 4.016 and 0.006 respectively. The calculated CR value is less than 0.1, therefore, the AHP approach is reliable in the assignment of the weights to the attributes. The AHP derived weights has been given in Table 4.

Table 4. AHP derived weights

Selection criteria	|RC|	EAB	*t*	Δ
Weights	0.373	0.373	0.205	0.049

3.2 TOPSIS and VIKOR based Ranking Results

TOPSIS and VIKOR ranking algorithms were implemented using the AHP derived weights and the results are shown in Table 5. The comparison of the TOPSIS and VIKOR ranking approaches has been shown in Fig. 2.

From Fig. 2, it can be deduced that FeCo@C and Co@C have been ranked as an efficient and cost-effective absorber by the TOPSIS and VIKOR approaches. The reason for their efficient absorption characteristics may be due to their good impedance matching and attenuation characteristics which allows the incident EM signals to enter into the interior of the absorber material and suffer multiple scatterings and reflections resulting in enhanced EM wave absorption. Cu@Ni and Fe@ZnO have been ranked as the worst absorbers owing to their small bandwidth, large thickness and larger deviation from the central frequency. The closeness between the two ranking systems has been calculated using the Spearman rank correlation co-efficient (δ) as given in Eqn. (15)[28].

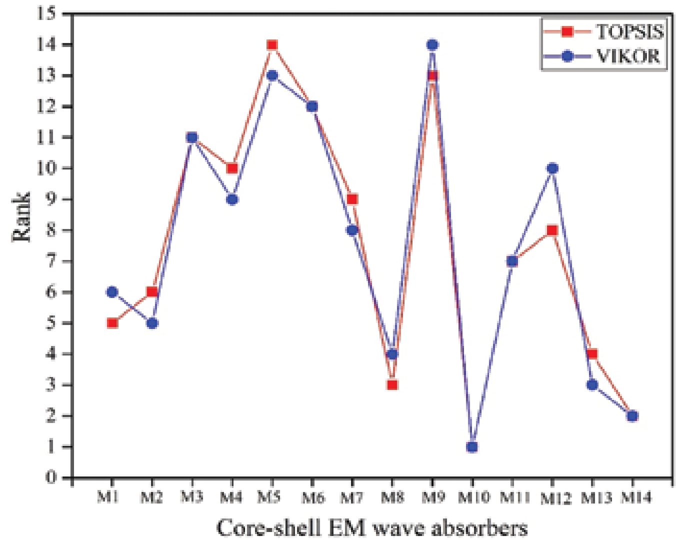

Figure 2. Comparison of core-shell EM wave absorbers using TOPSIS and VIKOR approaches.

$$\delta = 1 - \frac{6\sum_{x=1}^{s} D_R^2}{s(s^2-1)} \quad (15)$$

where, δ is the Spearman rank correlation co-efficient, *s* denotes the number of material available, D_R denotes the numerical difference between TOPSIS and VIKOR ranks. Spearman rank correlation coefficient (δ) of TOPSIS and VIKOR has been found to be 0.974 which indicates that both the methods yield comparably the same result.

4. CONCLUSIONS

In the present work, the AHP method has been successfully employed to determine the weights of the various attributes by subjective judgments. Both the TOPSIS and VIKOR methods used in this literature have predicted close results

Table 5. Comparison of TOPSIS and VIKOR ranking approaches

Material code	TOPSIS Analysis				VIKOR Analysis			
	P_j^+	P_j^-	Q_j	Rank	X_j	Y_j	Z_j	Rank
M1	0.140974	0.081344271	0.365891	5	0.572051	0.276623	0.50428	6
M2	0.147325	0.078209238	0.346773	6	0.5305	0.278368	0.467618	5
M3	0.168402	0.071660689	0.298508	11	0.640571	0.322288	0.699012	11
M4	0.151873	0.065353093	0.300853	10	0.732735	0.277358	0.666769	9
M5	0.199163	0.049132363	0.197879	14	0.707773	0.372843	0.90595	13
M6	0.172045	0.057189807	0.249481	12	0.647024	0.325448	0.714195	12
M7	0.152321	0.065604319	0.30104	9	0.699171	0.268573	0.608956	8
M8	0.104022	0.118018075	0.531518	3	0.427003	0.217806	0.196754	4
M9	0.179484	0.046890009	0.207135	13	0.801957	0.372843	1	14
M10	0.058734	0.193060081	0.766738	1	0.301244	0.210454	0.050839	1
M11	0.165935	0.07610471	0.31443	7	0.517342	0.322288	0.575958	7
M12	0.166938	0.074641546	0.308972	8	0.651123	0.316601	0.693817	10
M13	0.125025	0.120503989	0.490794	4	0.33412	0.249615	0.191987	3
M14	0.067361	0.162168534	0.706525	2	0.391918	0.192073	0.090545	2

in the ranking of the EM wave absorbers in 2-18 GHz range. Spearman's correlation coefficient (δ) has been found to be 0.974 indicating a nearly perfect association between the two ranking methods. Therefore, the present work successfully highlights the importance of AHP based TOPSIS and VIKOR approaches in the selection of efficient and low-cost EM wave absorbers.

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